# DETECTOR TESTS

# FOR

# THE LHC LUMINOSITY PROJECT

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on behalf of

the **CERN**-**LBNL** and the **CERN**-**LETI**

**COLLABORATION PROJECTS**

# Contents

# Concepts and Developments

- **Instrument TAN (TAS) Absorbers at LHC High Luminosity IPs**
  **TAN only : $\Rightarrow$ Luminosity**
  **TAN and TAS : $\Rightarrow$ Luminosity $+$ Crossing Angle $+$ IP Position**

- **@ TAN: Detect Flux of Neutral particles from IPs**
  **@ TAS: Detect Flux of Charged particles**

- **Detectors**
  **Ionisation Chamber / LBNL project**
  **CdTe Solid state / SL-BI/LETI project**

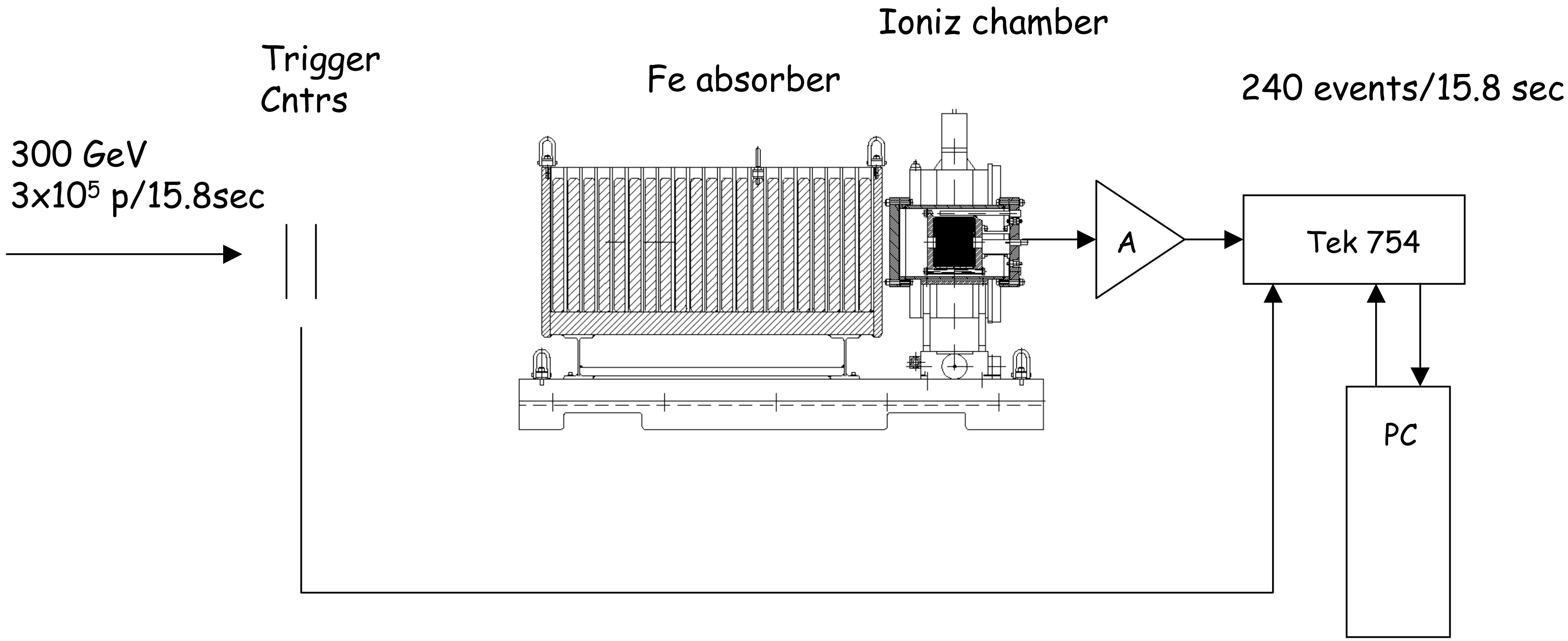
# Prototype Detector Tests

- **Simulate Electro-magnetic Showers**
  initiated by **Neutrals in TAN**

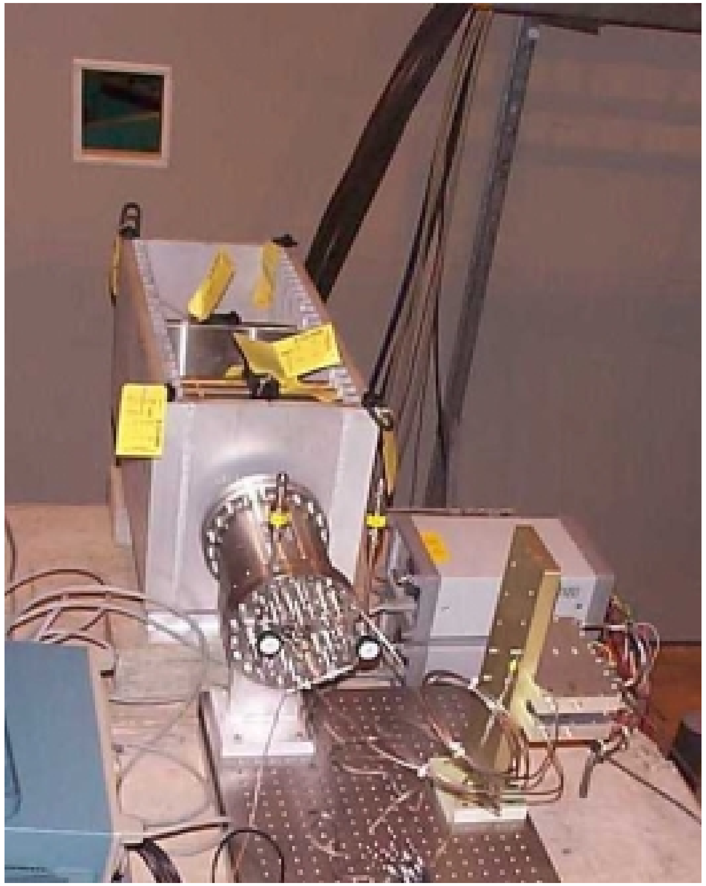
- **Modular Fe Absorber on H4 SPS 300 GeV $p$-Beam**
  **Prototype IC @ Shower Maximum**

- **Test Detector Sensitivity and Speed**
  **Compare Detector Performance to Design**
  **Compare signal amplitudes** with **MARS predictions**

# Schematic of setup in SPS H4, Sep. 2001



# Photo of the setup in SPS H4 300 GeV proton beam, Sep 2001



# Hadronic/em showers

- The hadronic energy incident on the TAN per pp interaction in LHC is ~ 750 GeV
- The flux of mips at the shower maximum in the TAN is ~ linear function of incident hadron energy
- => single 300-450 GeV protons from SPS can be used for realistic tests of response of detector to single pp interactions in LHC
- The MARS code (N. Mokhov) is used for shower simulations of LHC and SPS H4 test beam conditions

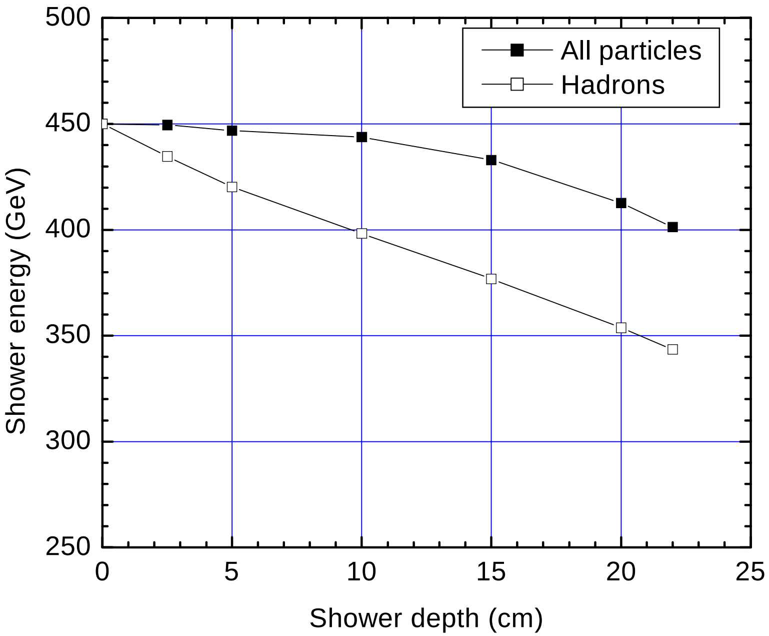
## Use the MARS code to

- Understand the energy flow in hadronic/em showers
- Understand the energy deposition by hadronic/em showers
- Estimate the ionization chamber signal from the flux of ionizing radiation

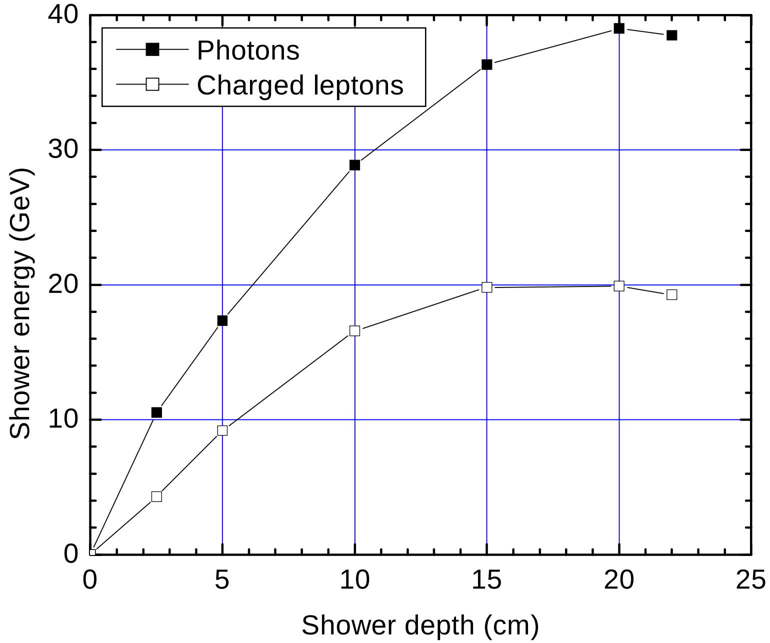
# Shower energy is carried predominantly by hadrons

## Primary proton energy = 450 GeV

(a) Hadrons

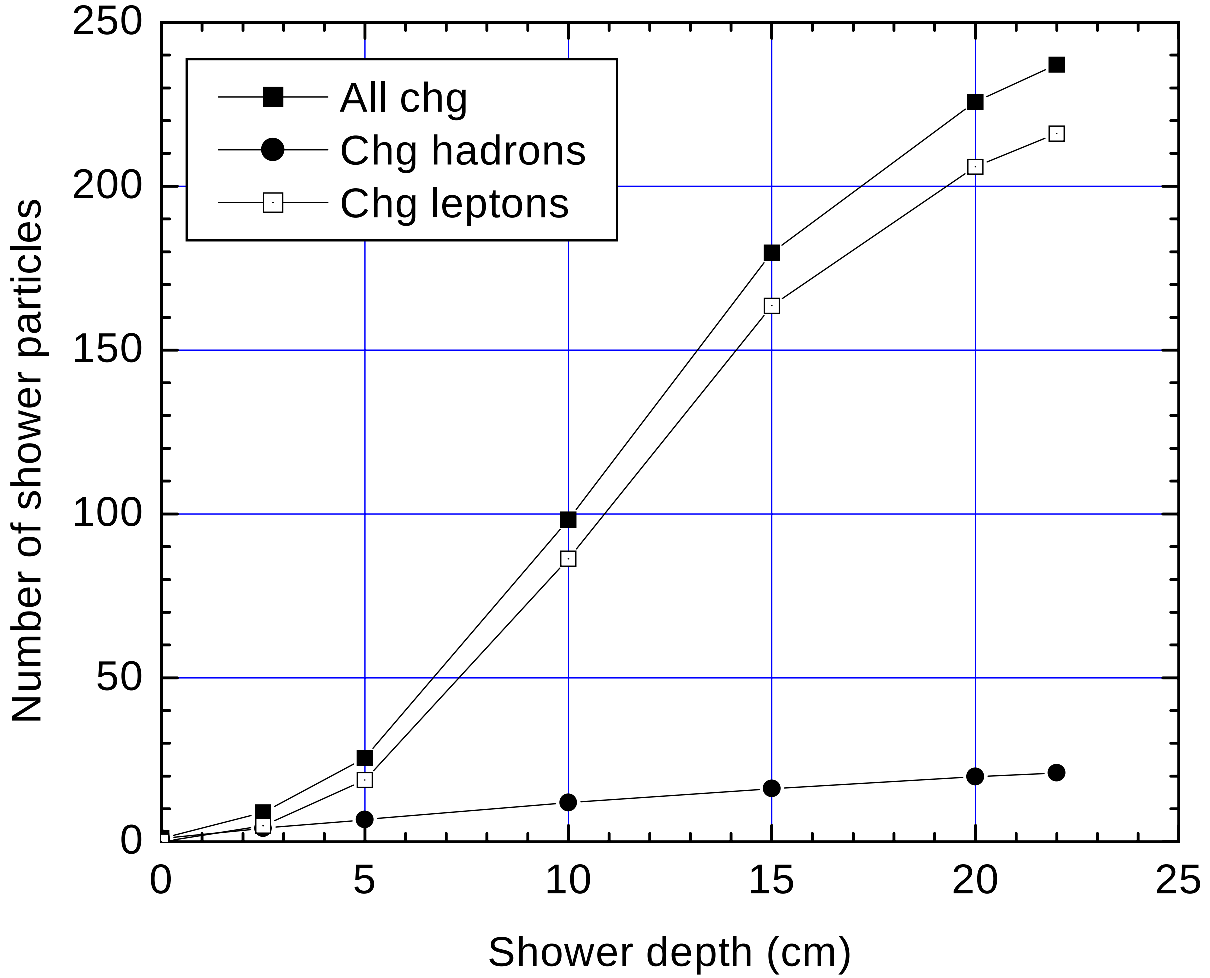



(b) Charged leptons and photons

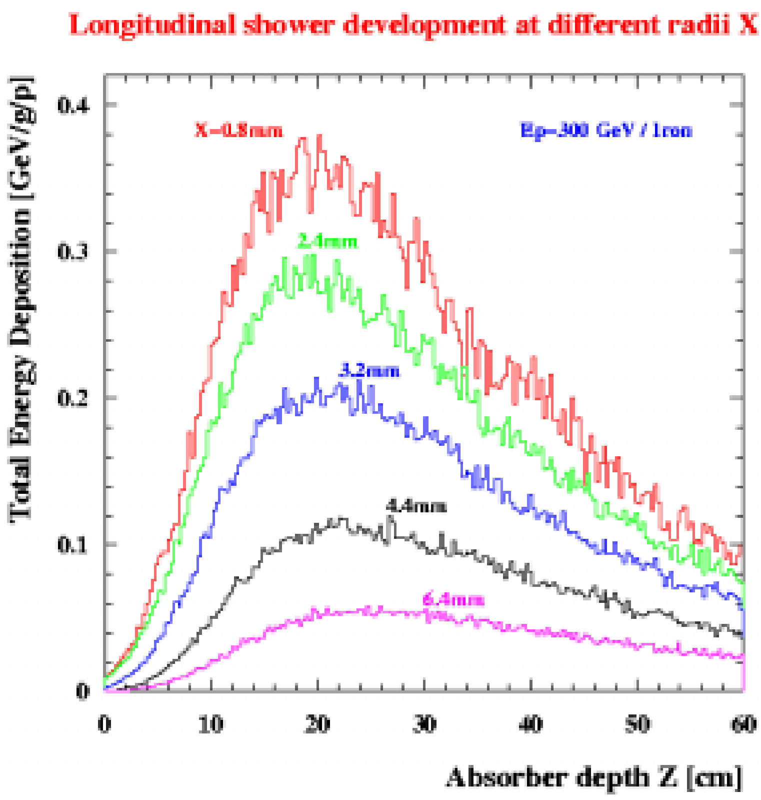


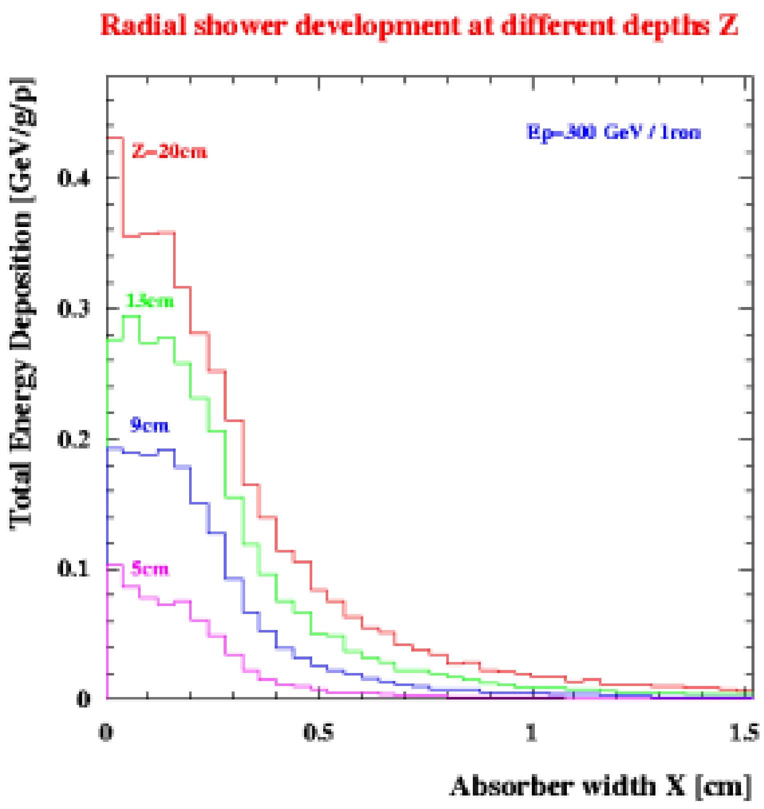
The charged particle flux (and ∴ energy deposition) is dominated by leptons (mostly $e^{+}+e^{-}$)

Primary proton energy = 450 GeV



# Ionization energy deposition, $E_p$ = 300 GeV



# Flux and mean energy of particles near the shower maxima of 300 and 450 GeV primary protons

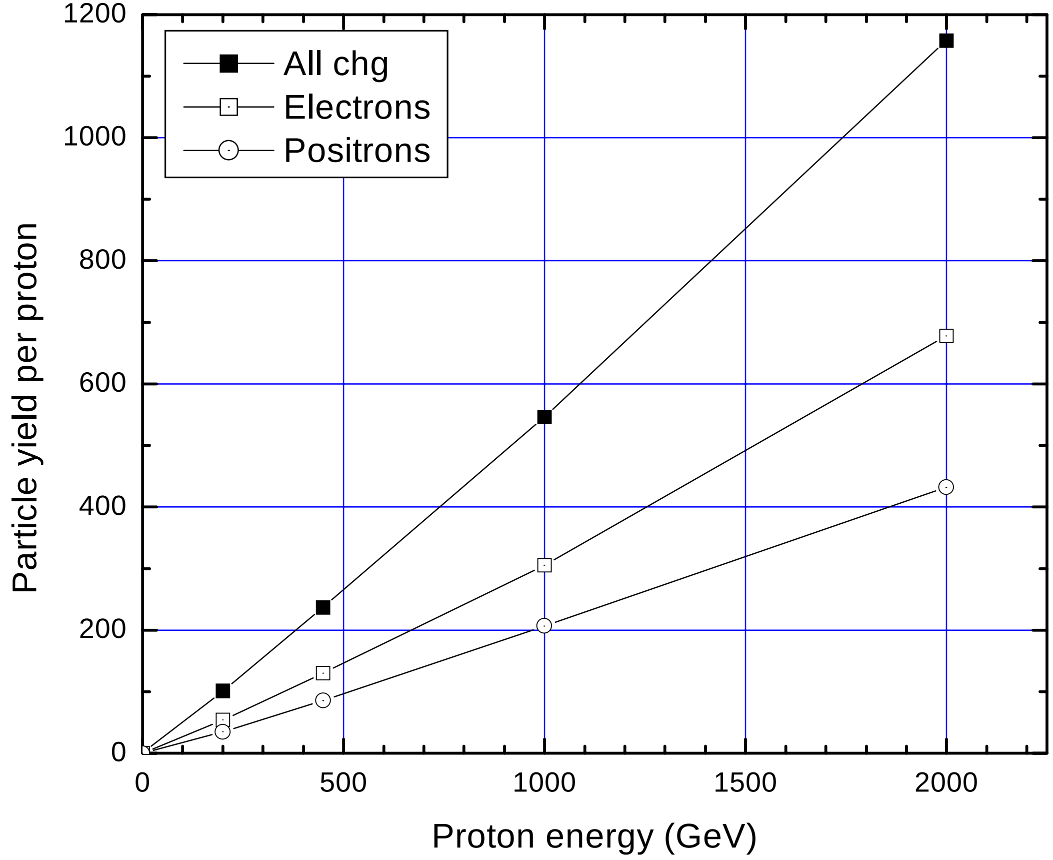
## (a) 300 GeV proton

| particle | Flux per proton | Mean energy, MeV |
|---|---|---|
| $e^-$ | 84.6 | 73.0 |
| $e^+$ | 55.4 | 108.0 |
| $\pi^-$ | 5.0 | 5,376 |
| $\pi^+$ | 5.7 | 6,440 |
| $K^-$ | 0.50 | 6,892 |
| $K^+$ | 0.59 | 8,501 |
| p | 3.4 | 35,795 |
| n | 17.0 | 1,970 |
| $\gamma$ | 1,738 | 14.4 |
| All chg. | 155.2.0 | - |

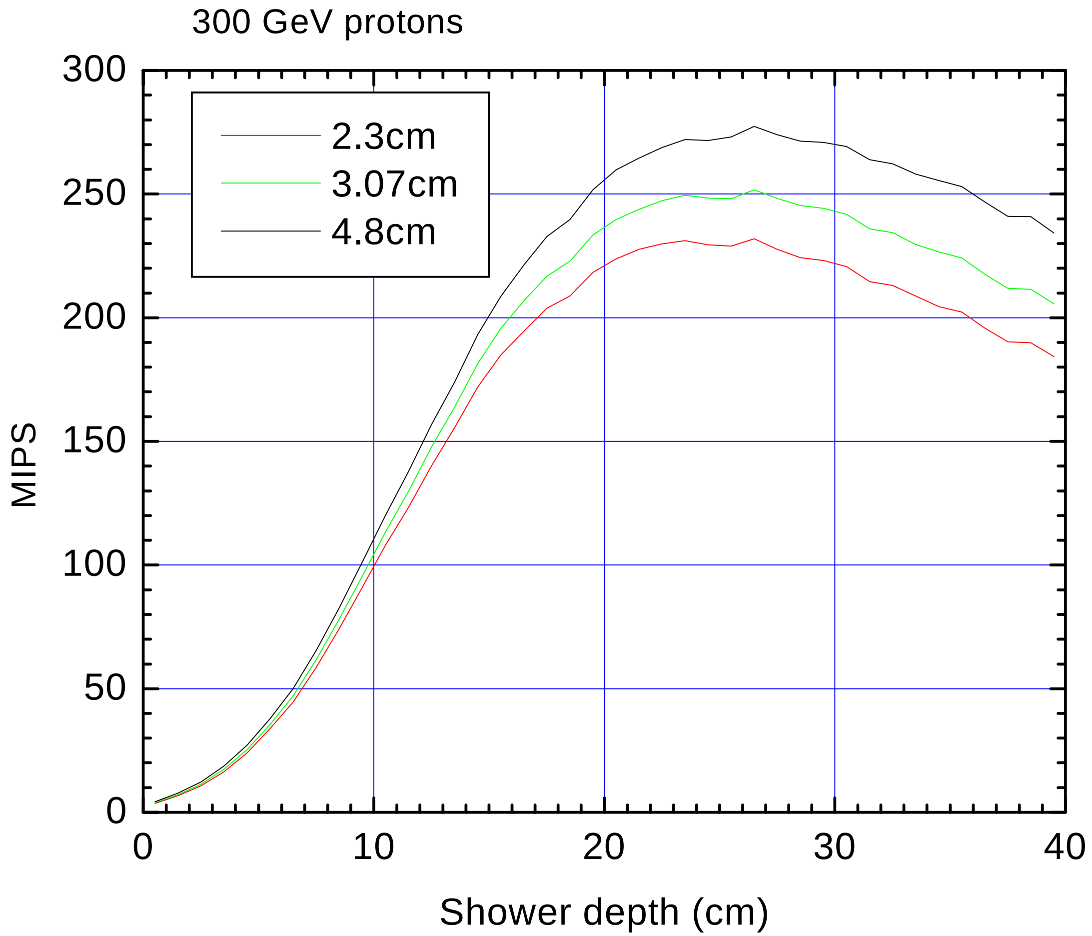
## (b) 450 GeV proton

| particle | Flux per proton | Mean energy, MeV |
|---|---|---|
| $e^-$ | 130.2 | 75.2 |
| $e^+$ | 85.9 | 109.8 |
| $\pi^-$ | 6.9 | 6,500 |
| $\pi^+$ | 8.0 | 7,820 |
| $K^-$ | 0.74 | 7,988 |
| $K^+$ | 0.78 | 10,812 |
| p | 4.4 | 39,031 |
| n | 23.2 | 2,121 |
| $\gamma$ | 2743.5 | 14.0 |
| All chg. | 237.0 | - |

# Particle yield at the shower maximum is nearly a linear function of $E_p$



# Ionization equivalent MIPS flux versus shower depth in Fe per 300 GeV proton

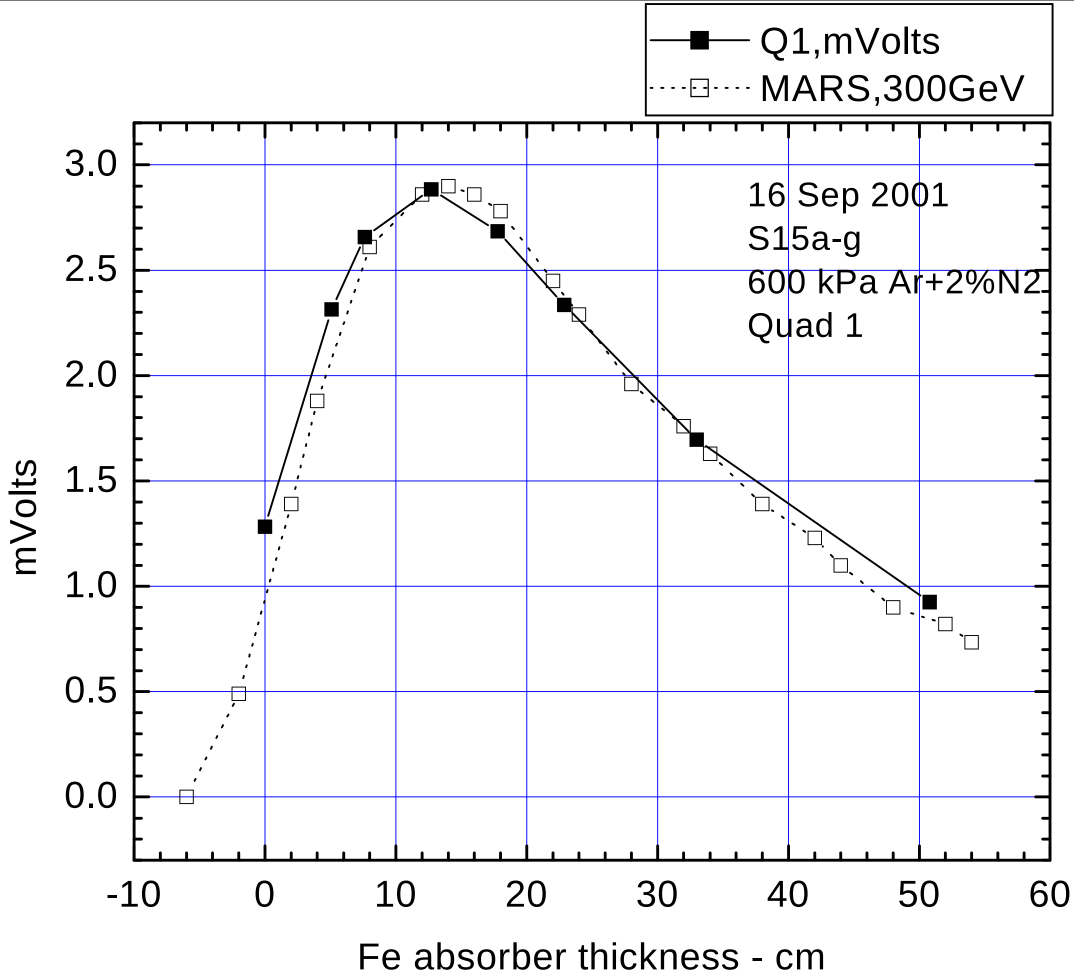


# Predicted signal at shower maximum in 300 GeV proton beam

- 6 atmos Ar+2% $N_2$ => 6x97 = 582 electron-ion pairs/cm-mip
- Ten 0.5mm gaps => 0.5x582 = 291 electrons/mip
- 231 mips/p at shower max => $6.7 \times 10^4$ electrons/p
- Transfer function 0.45μV/e
- Ballistic deficit ~ 3
- Cable attenuation = 20%
- Expected signal

  => $0.5 \times 6.7 \times 10^4 \times .45 \times 10^{-6} \times 0.8 / 3 = 4.0$ mV

# Fe absorber thickness scan, MARS data normalized to peak of experimental data



# (1) Status Summary

- Signal and noise requirements have been met
- 40MHz bandwidth for measurement of the luminosity of individual colliding bunch pairs has been met
- Agreement with MARS shower simulations is good
- Behavior of ionization chamber with variation of gas pressure and position in the beam is as expected

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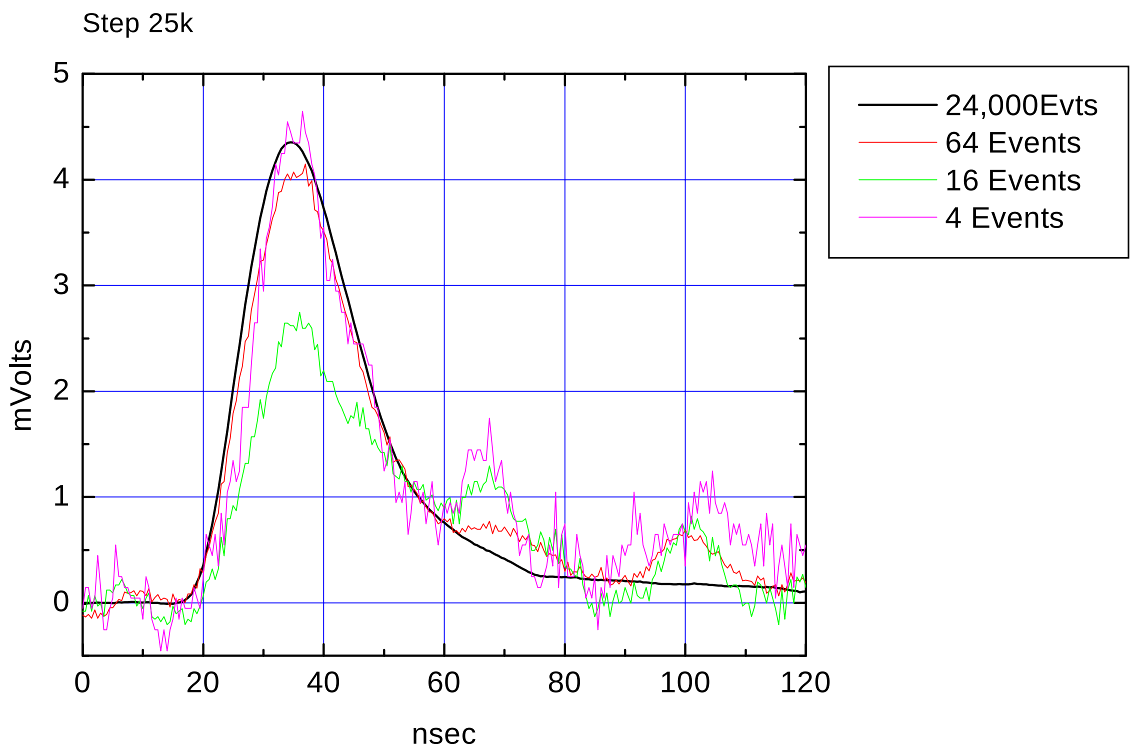
# Waveform averaging improves proton shower S/N ratio



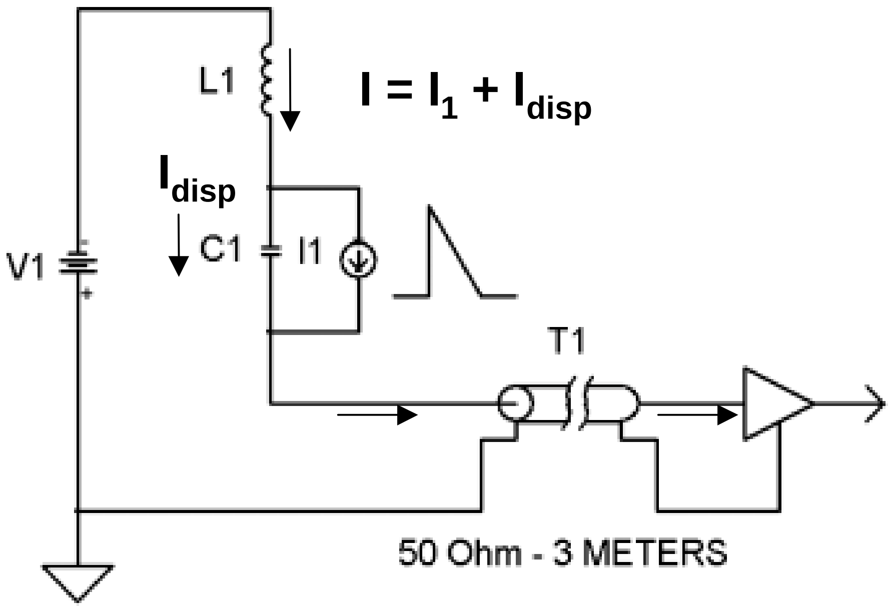

- Pulse height 4.2mV in good agreement with MARS prediction 4.0 mV

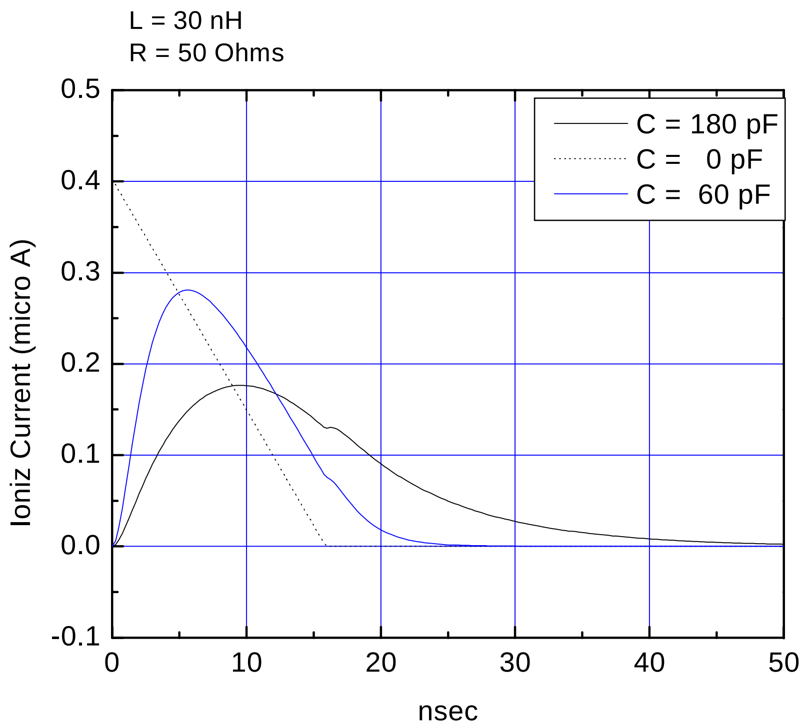
# How short does the pulse need to be for 40MHz lumi measurement?

--- in general there is not a simple answer

- Full width < 25 nsec
  - No interference of bunches $V_{peak}$ => L
- Full width < 25 ns + peaking time
  - No interference at peaks of bunches $V_{peak}$ => L
- Peaking time < 25 ns
  - No interference of trailing pulses with the peak of the leading bunch in a bunch train
  - Subtraction from head to tail of bunch train deconvolves overlap
- Peaking time > 25 ns
  - subtraction from head to tail of bunch train still deconvolves overlap but more involved, accuracy of fit and propagation of noise becomes an issue

# Excitation of normal modes of the ionization chamber broaden the current pulse

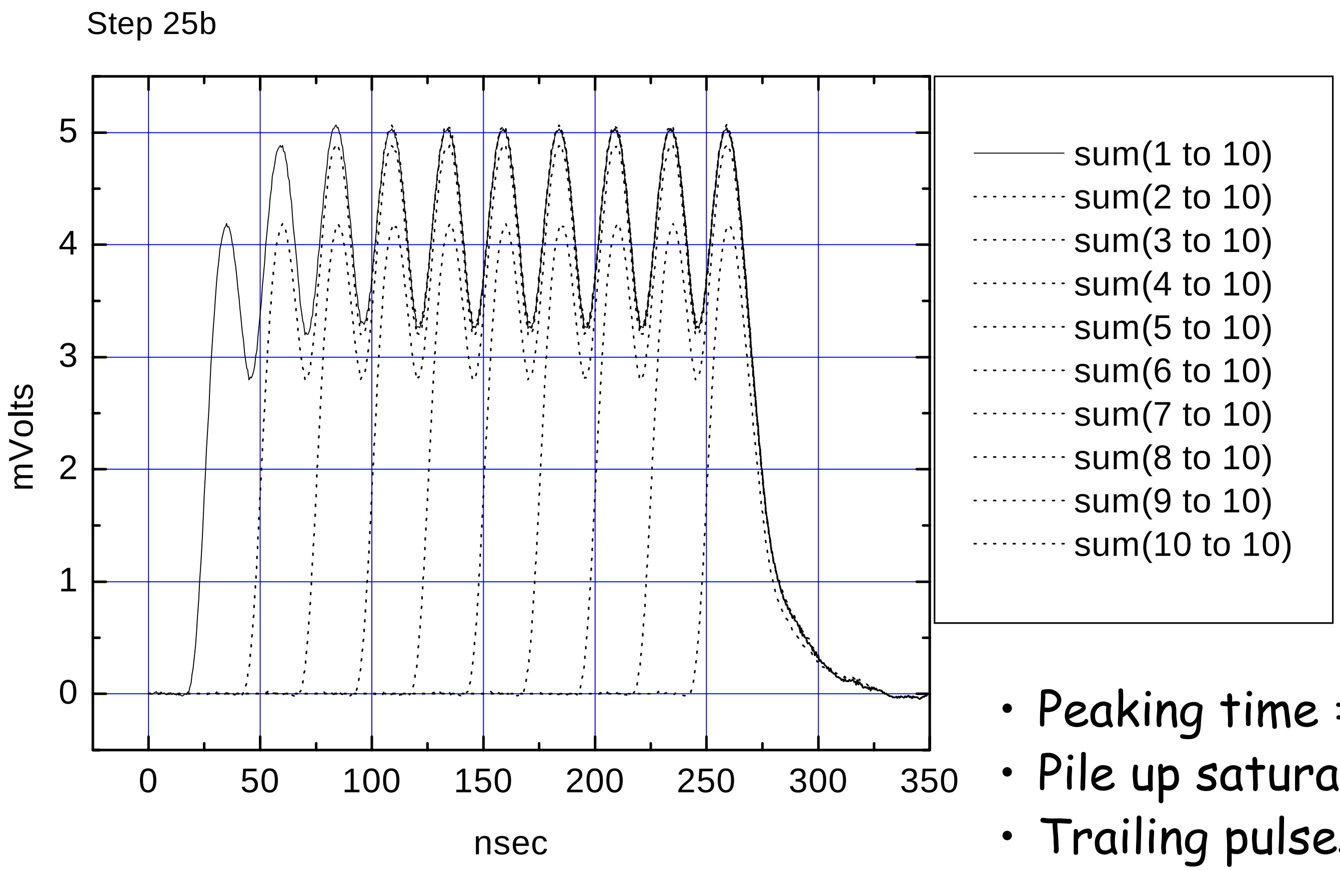



$I_1$ = ionization current (electrons)

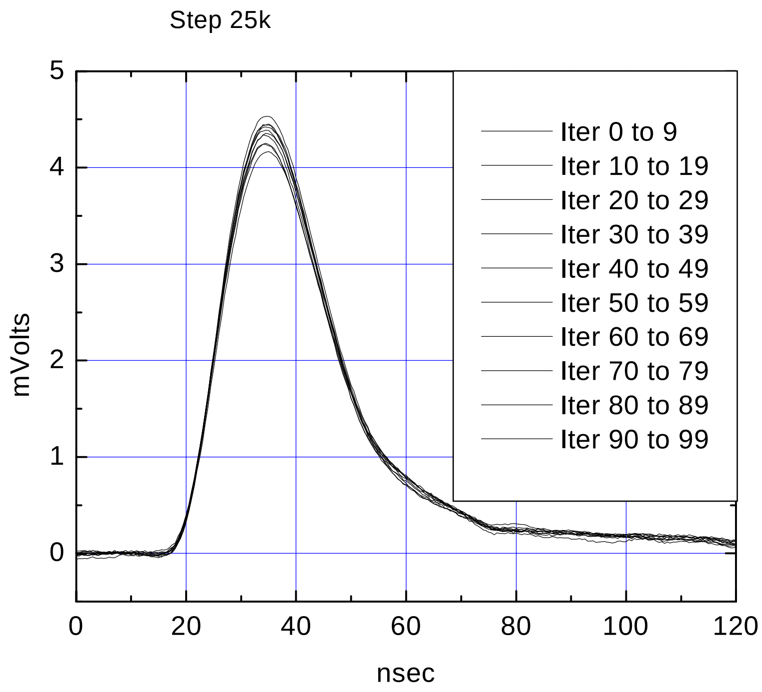
$C_1$, $L_1$ = ionization chamber capacitance and inductance

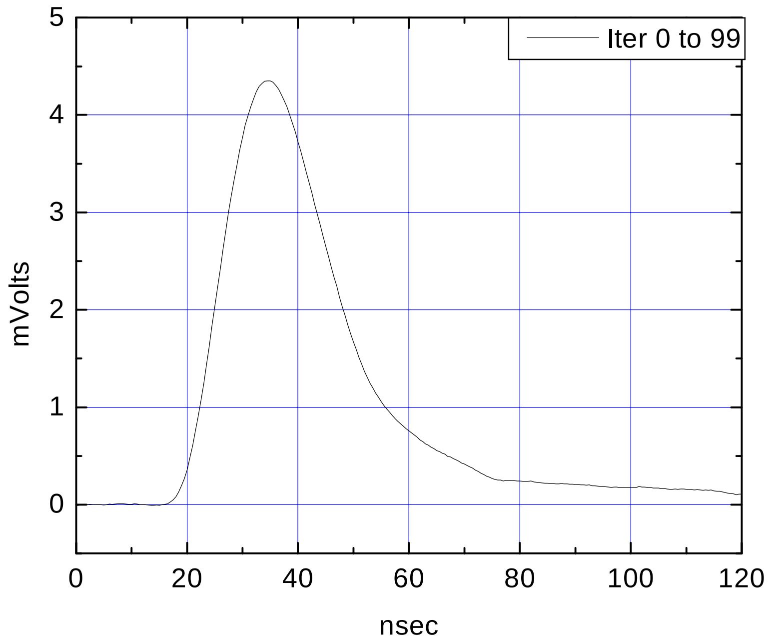
# A typical proton shower waveform delayed 25 ns and added to itself 10 times



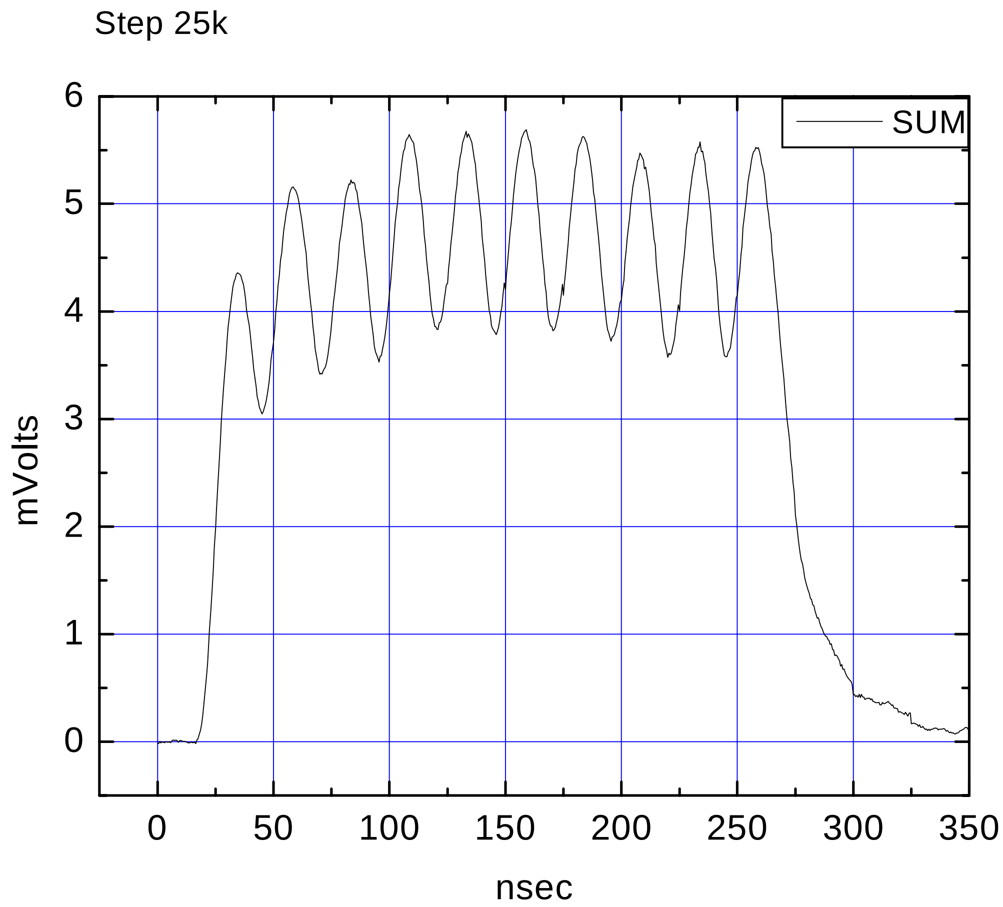

- Peaking time = 16ns < 25ns
- Pile up saturates in 3 pulses
- Trailing pulses do not interfere with the peak of the leading pulse

# Synchronous overlay of ten 2.4k event waveforms and the 24k mean waveform

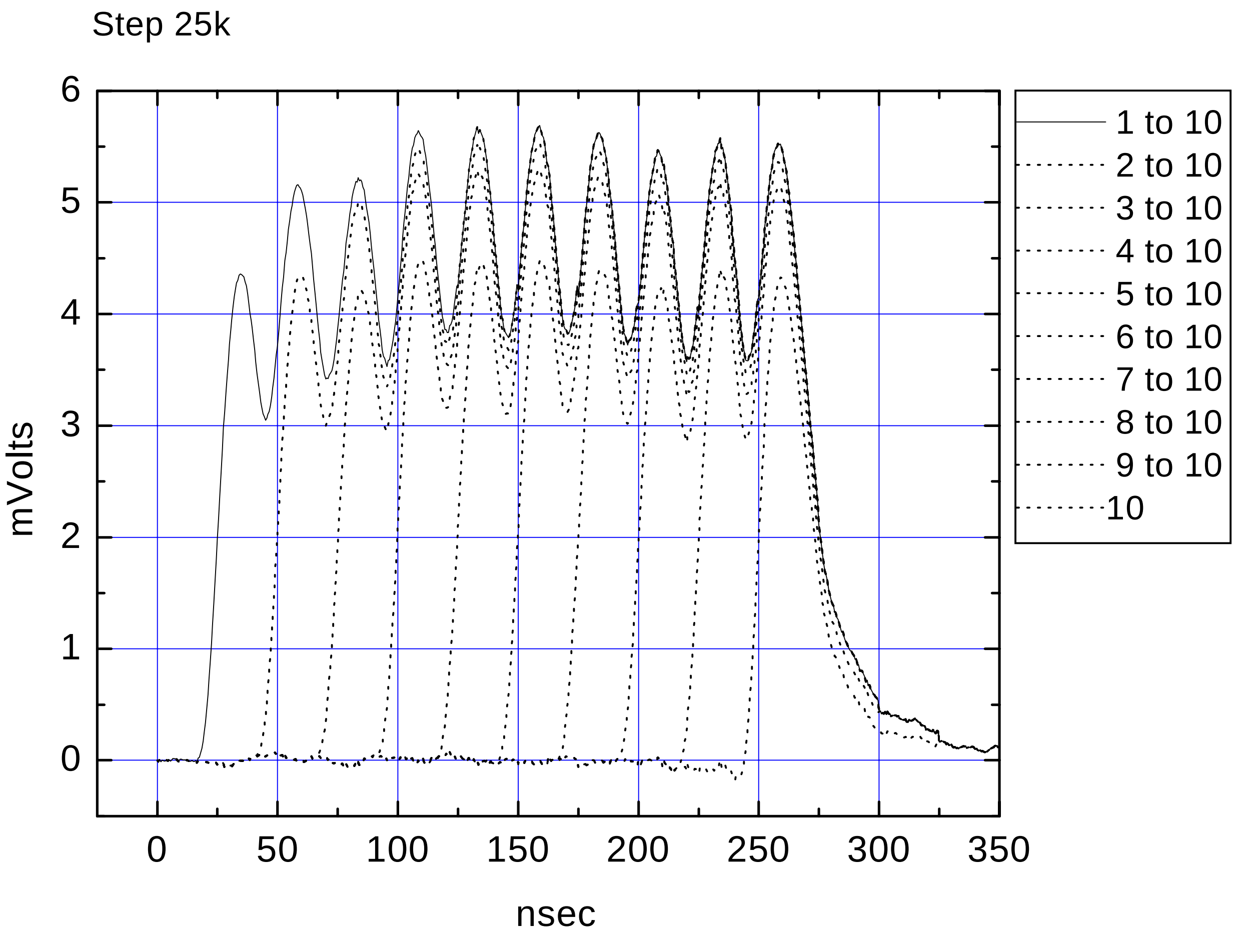


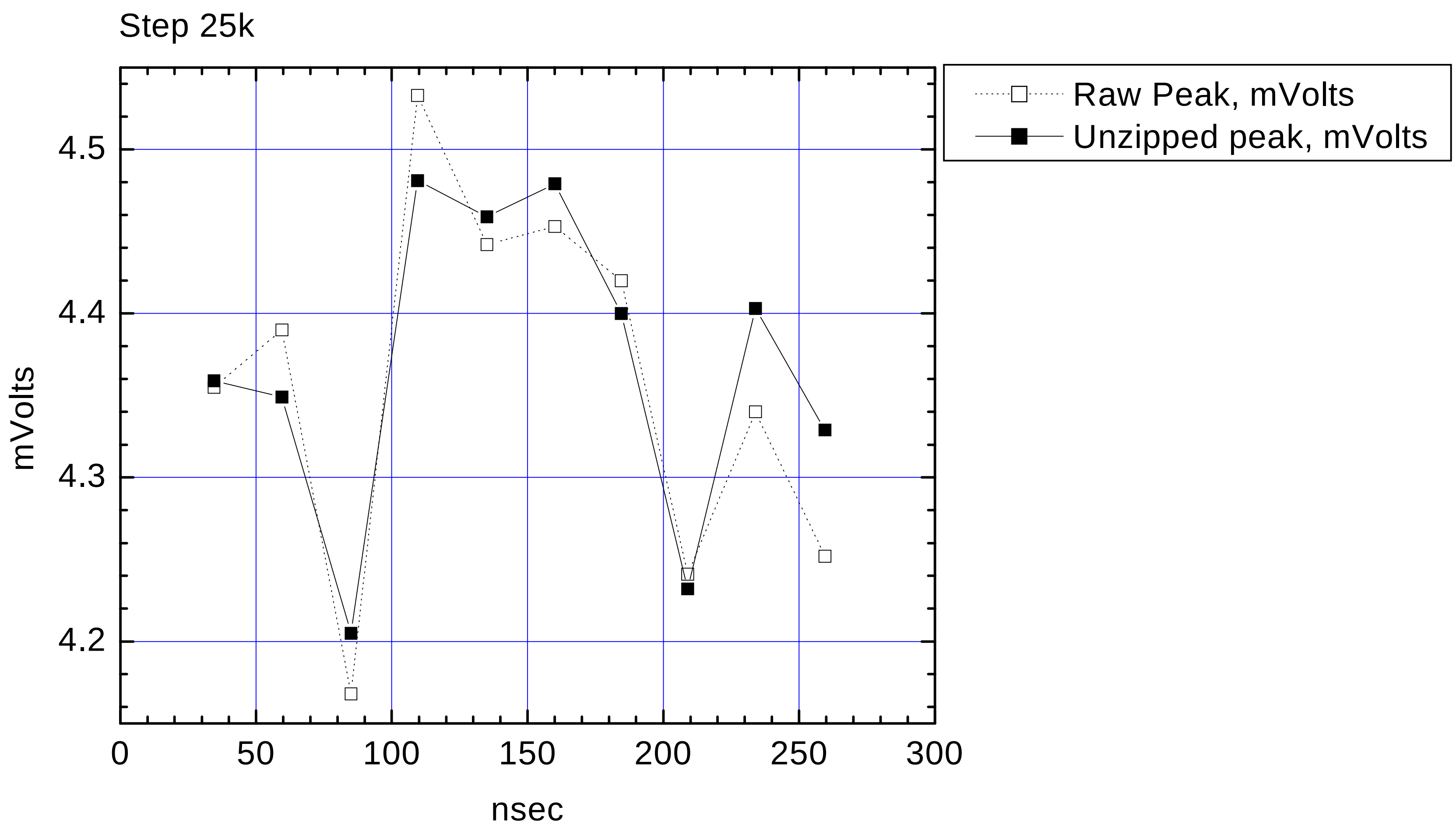
# Ten pulse summation, pulses successively delayed by 25ns



# Successively fit and subtract the leading pulse



# Unzipped and raw peak heights track one another with statistical error



# Outlook / CdTe

- **CdTe signal response rapidity**

  **matches 40 MHz data acquisition**

- **Sensitivity above 100 electrons per micron/MIP**

  **allows simple design**

- **Irradiation tests up to $10^{16}$ n/cm$^2$ demonstrated**

  **no significant modification in carrier lifetime**

- **Performance tests after irradiation up to $10^{17}$ n/cm$^2$**

  **are being planned**

# Outlook / Ionisation Chamber

- **Signal and noise requirements have been met**
- **40 MHz bandwidth for bunch-by-bunch luminosity measurement looks at reach**
- **Good agreement with MARS Shower simulations and expected signal amplitude**
- **Performance vs. gas pressure is as expected.**

# Outlook / Ionisation Chamber: what next

- Parasitic impedances, ground plane capacitance
- Pulse width reduction
- Gas purity monitoring
- More MARS studies:

  TAN/TAS Sensitivity to IP Crossing Angle and Transverse Position

  Longitudinal Magnetic Fields in ATLAS and CMS
- Data acquisition SW, Integration with LHC Operation
- Implement HW and SW for Lumi Optimisation algorithms